ESTIMATION AND CORRECTION OF SYSTEMATIC MODEL ERRORS IN GFS

DEPARTMENT OF
ATMOSPHERIC &
OCEANIC SCIENCE

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Estimating and correcting GFS bias

We proposed an R2O project to:

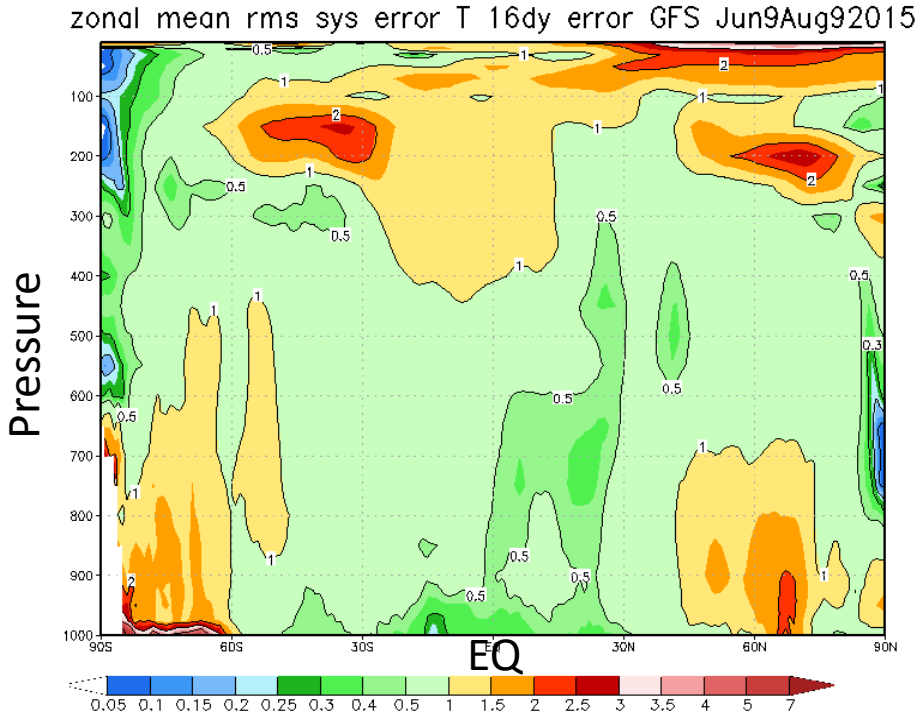
1. Estimate the GFS mean and diurnal systematic errors
2. Explore impact of online (compared to standard offline) corrections
3. Provide guidance to monitor the impact of improved physical parameterizations

Systematic errors and past studies

Systematic model errors (SME)

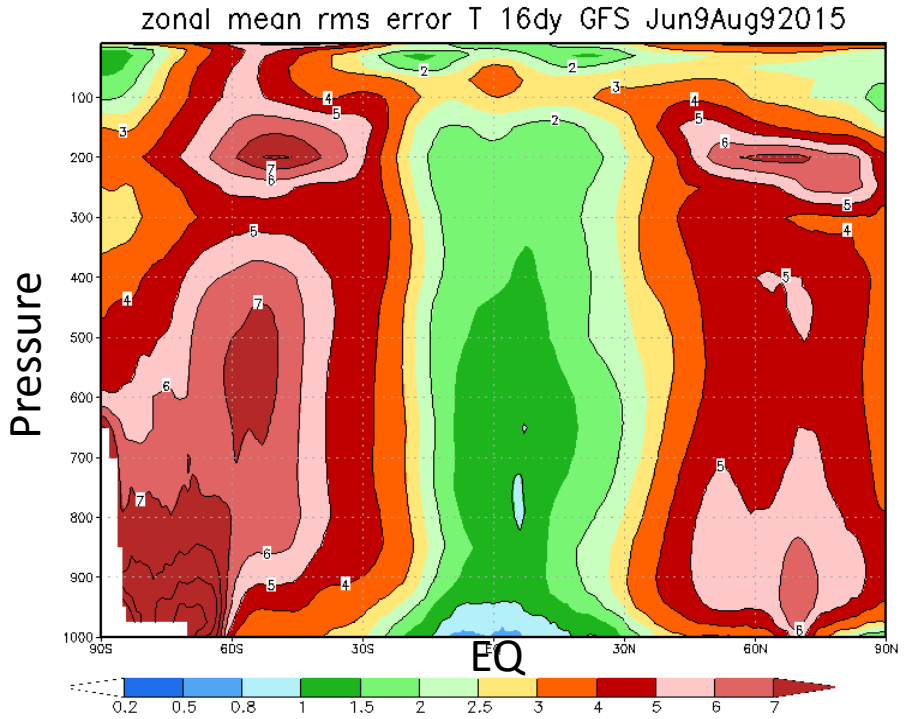
Range of RMS T systematic errors is ~1/3 of total RMS T error range after 2 weeks

RMS Systematic errors GFS



ΔT(systematic) ~ 0.5 -3K

RMS Total errors GFS



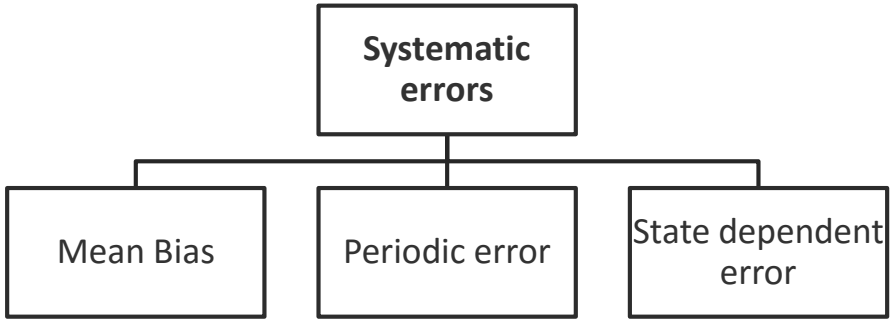
ΔT(total) ~ 1.5 -9K

Image courtesy: Glenn White

Systematic Model Error Correction

Offline Correction

- Physical origin obscured as errors grow non-linearly after short time



Online correction

- Reduces non linear error growth of bias
- Continuously corrected forecasts at all lead times
- Large forcing might disturb physical balance of model variables

Previous studies

Johansson and Saha (1989)	• Both methods removed systematic model errors • Online method reduced random errors significantly
Saha (1992)	• Online method performs as well as offline but doesn't reduce random errors
Li et al. (2009)	• Online bias removal with additive noise enhance the performance of LETKF, outperform the inflation schemes • Performs well in data sparse region
DelSole et al. (2008)	• Online method reduced systematic model errors • Didn't improve random errors

Previous studies

Danforth and Kalnay (2007, 2008a and 2008b)

- Time averaged analysis correction:

$$\dot{\mathbf{x}} = M(\mathbf{x}) + \frac{\langle \delta \mathbf{x}_6^a \rangle}{6\ \text{hr}} \equiv M^+(\mathbf{x}),$$

- Periodic component correction (diurnal correction): linearly interpolated leading EOFs (low dimension approach)

- State dependent correction: introduced new method using SVD of coupled analysis correction and forecast state anomalies (low dimension approach)

We plan to use these approaches to correct the GFS systematic errors

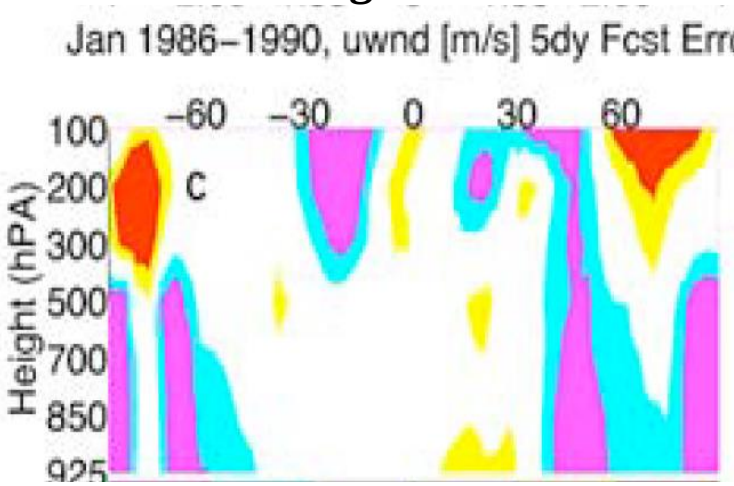
DK07, DK08a and DK08b Results

Online correction performance was slightly better than the operational statistical method applied a posteriori

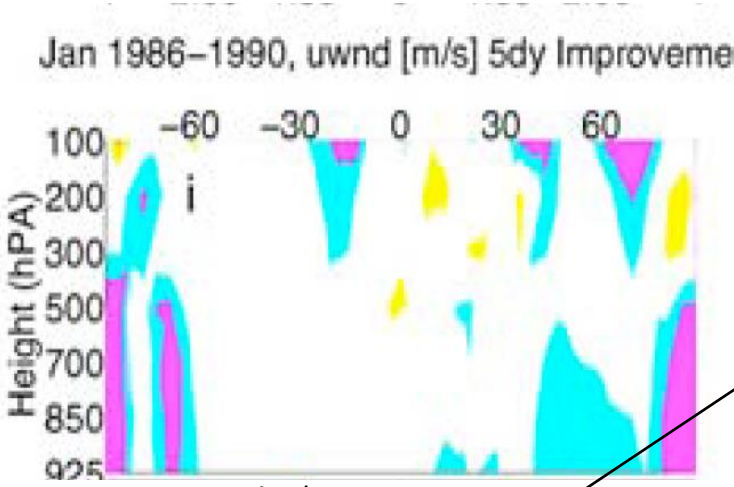
DK07, DK08a and DK08b Results

Zonally averaged 5 day forecast error U-wind

Original model

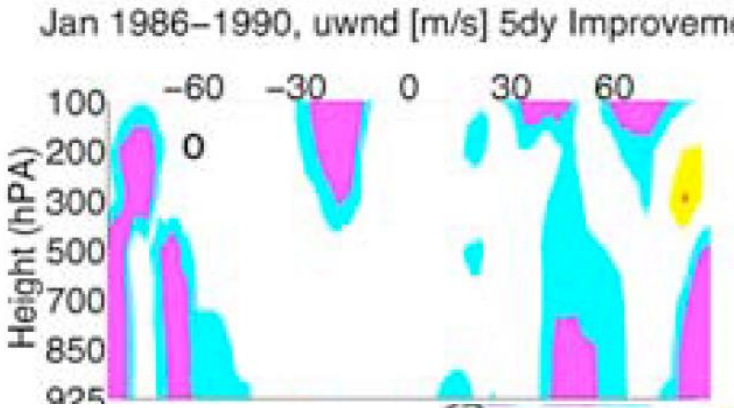


Online corrected

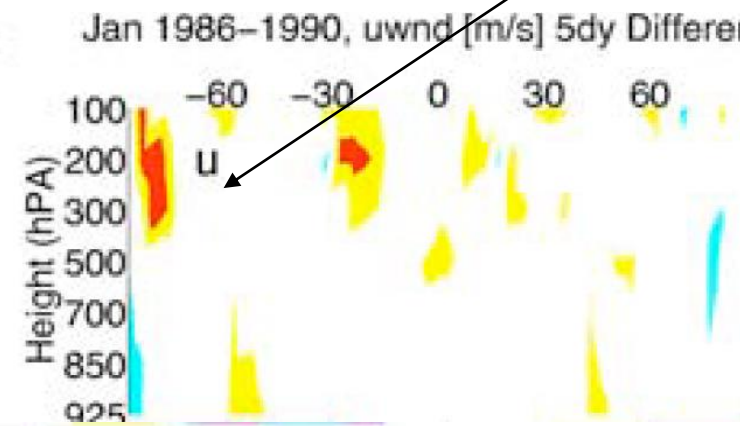


Online correction slightly better than offline

Offline corrected



Difference

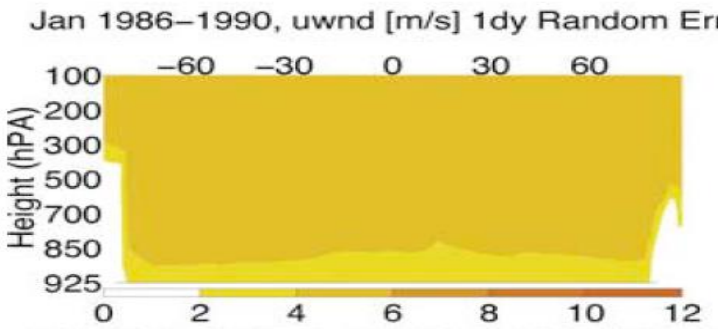


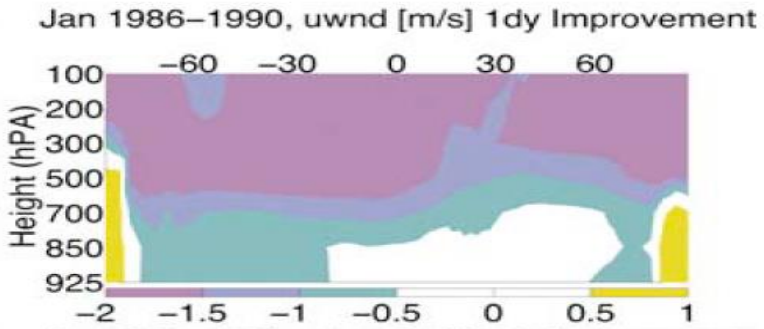
Correcting bias also reduces random errors

Non-constant errors U-wind (m/s)

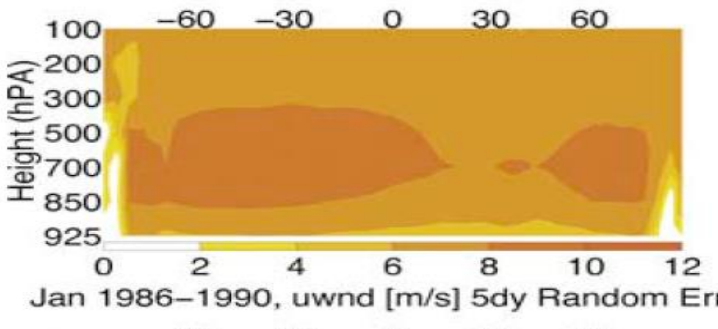
Original Model | **Online Correction**

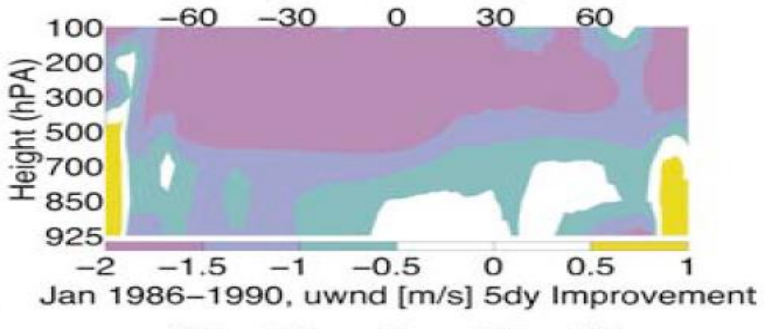
1 day



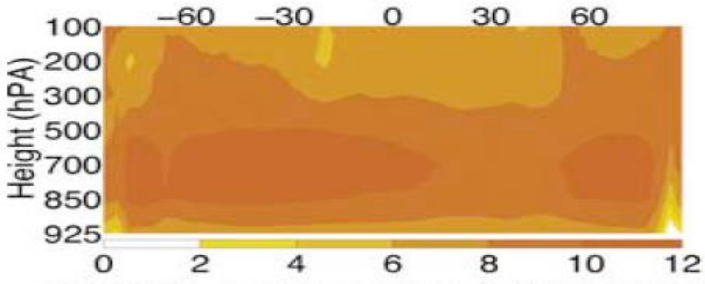


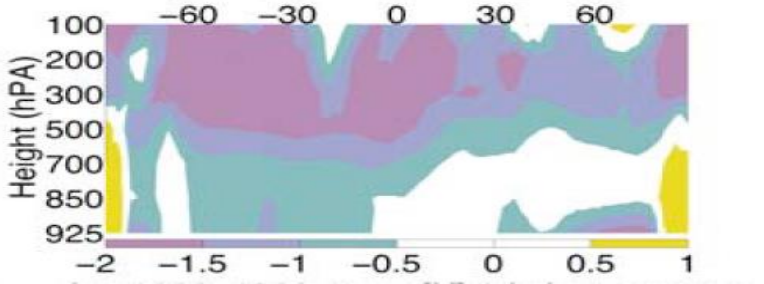
3 day





5 day





Application to GFS

Application to GFS

- Estimate the GFS systematic errors
  - Mean
  - Diurnal
- Check robustness: compare 2012, 2013, 2014
- Explore low dimensional approaches (e.g. diurnal cycle)
- Explore error sensitivity to resolution

Methods, Model and Data

Bias Calculation

- **Analysis Increment (AI) =Analysis(A)-Background(B)**
- Background contains information about errors **before they grow non-linearly**
- Best estimate of error growth due to model bias in 6 hour
- Estimate 6 hour model bias using the average analysis increments
- Averaged over 4 seasons of 2012, 2013 and 2014 calculated for surface pressure and temperature (T), specific humidity (q), and winds

Data and Model

- Operational data assimilation 6 hour forecasts and analysis
- Model Resolution : T574
- Data used was projected on **T254L64**
- Model levels : Hybrid sigma coordinates

$$P = (P_s * \sigma_1) + \sigma_2$$

- **Major changes in model:** May 2012. The data assimilation system moved from Gridpoint Statistical Interpolation to the hybrid system

Results

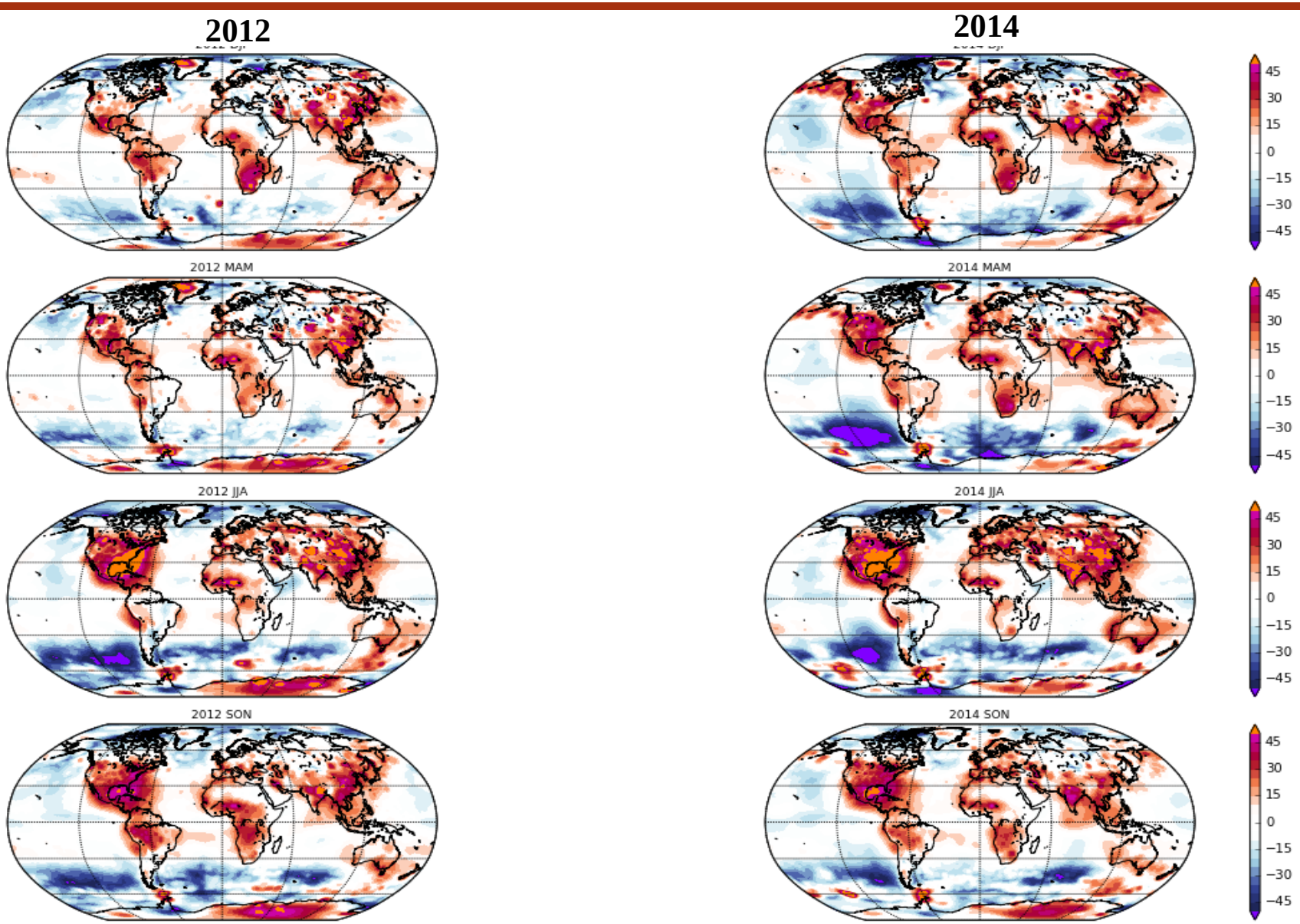
Seasonal Mean Bias: P_s (mb)

DJF

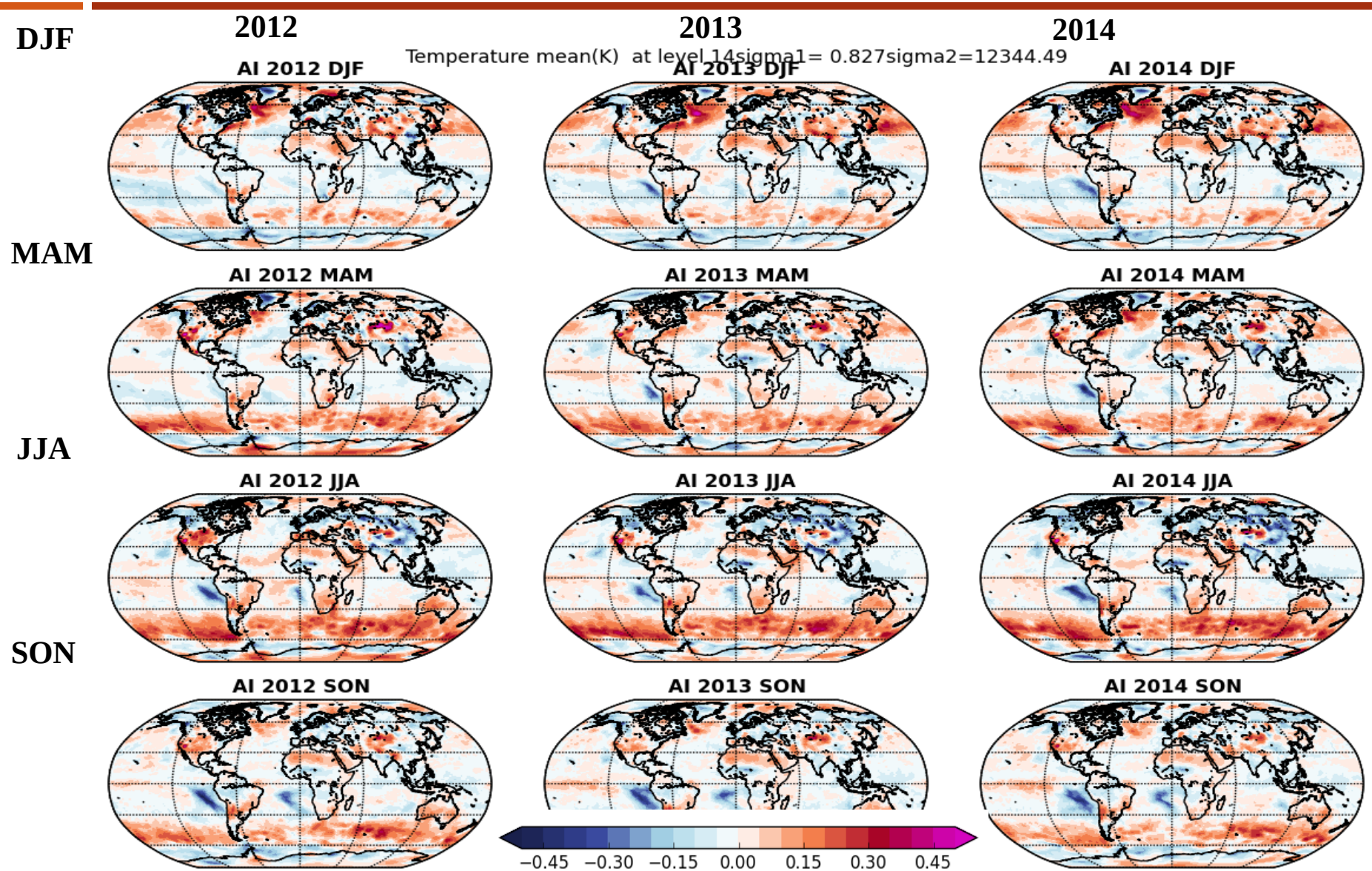
MAM

JJA

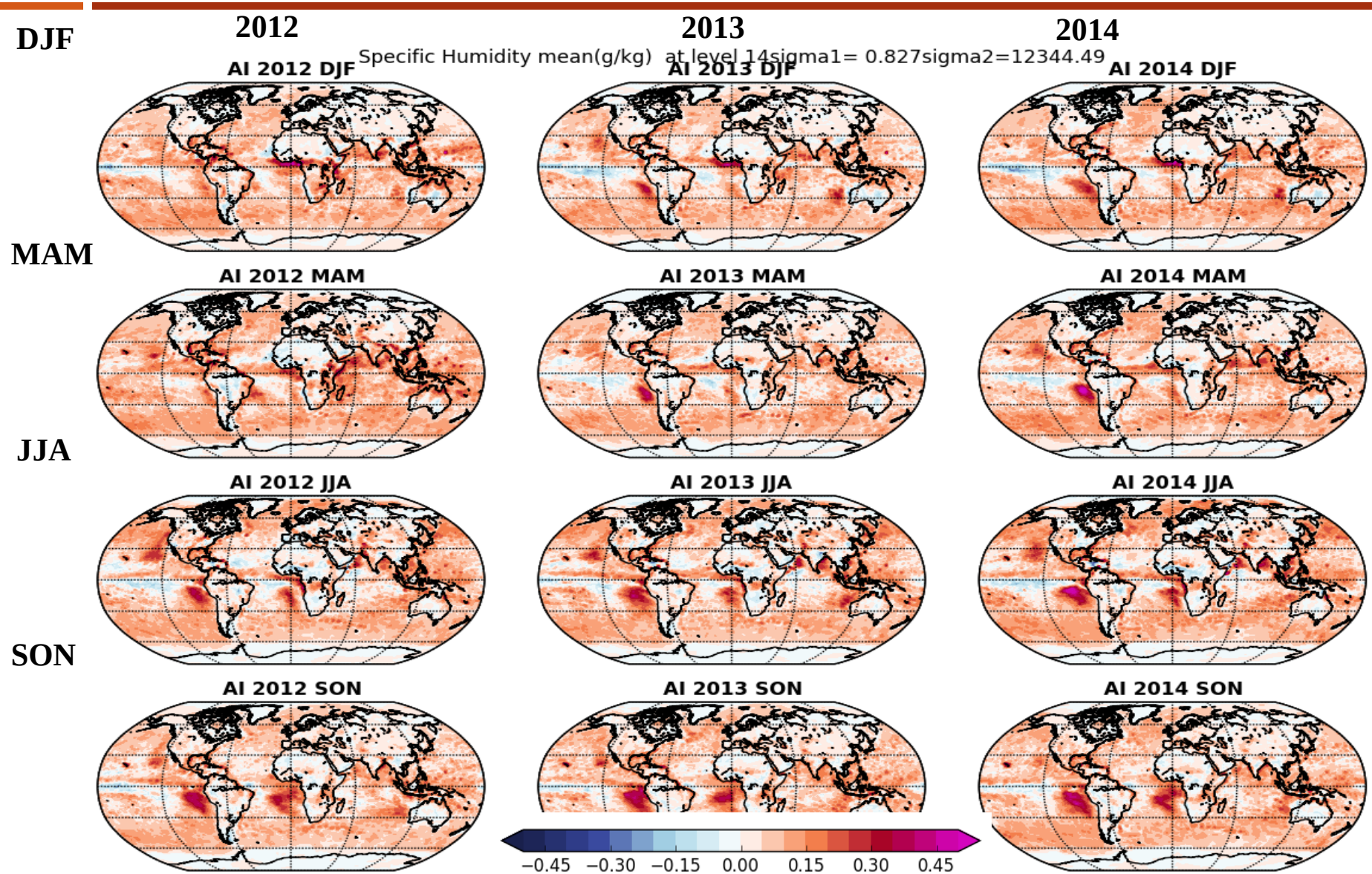
SON



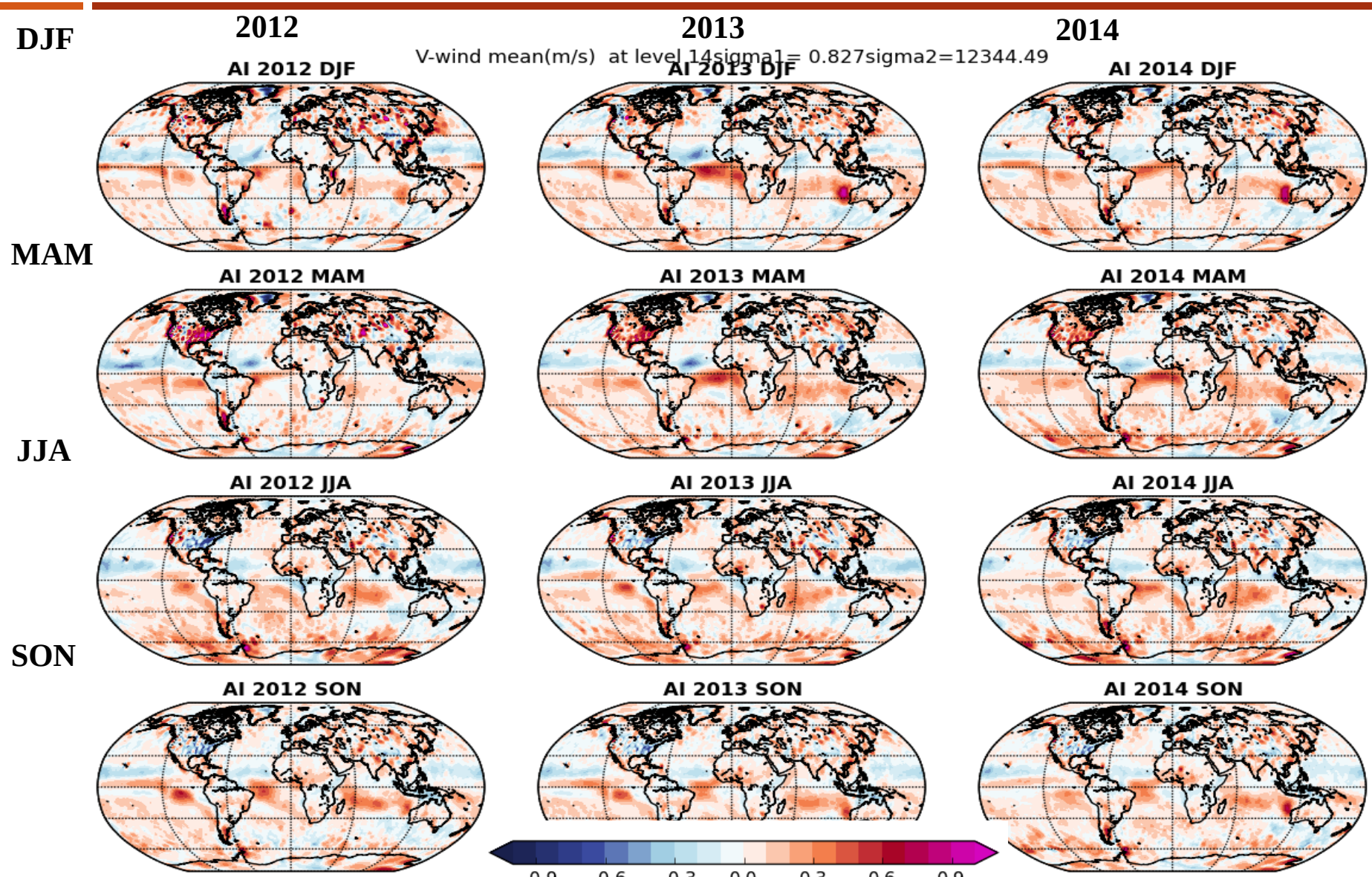
Seasonal Mean Bias: T (K) at ~850 mb



Seasonal Mean Bias: Q (g/kg) ~850 mb



Seasonal Mean Bias: V (m/s) at ~850 mb



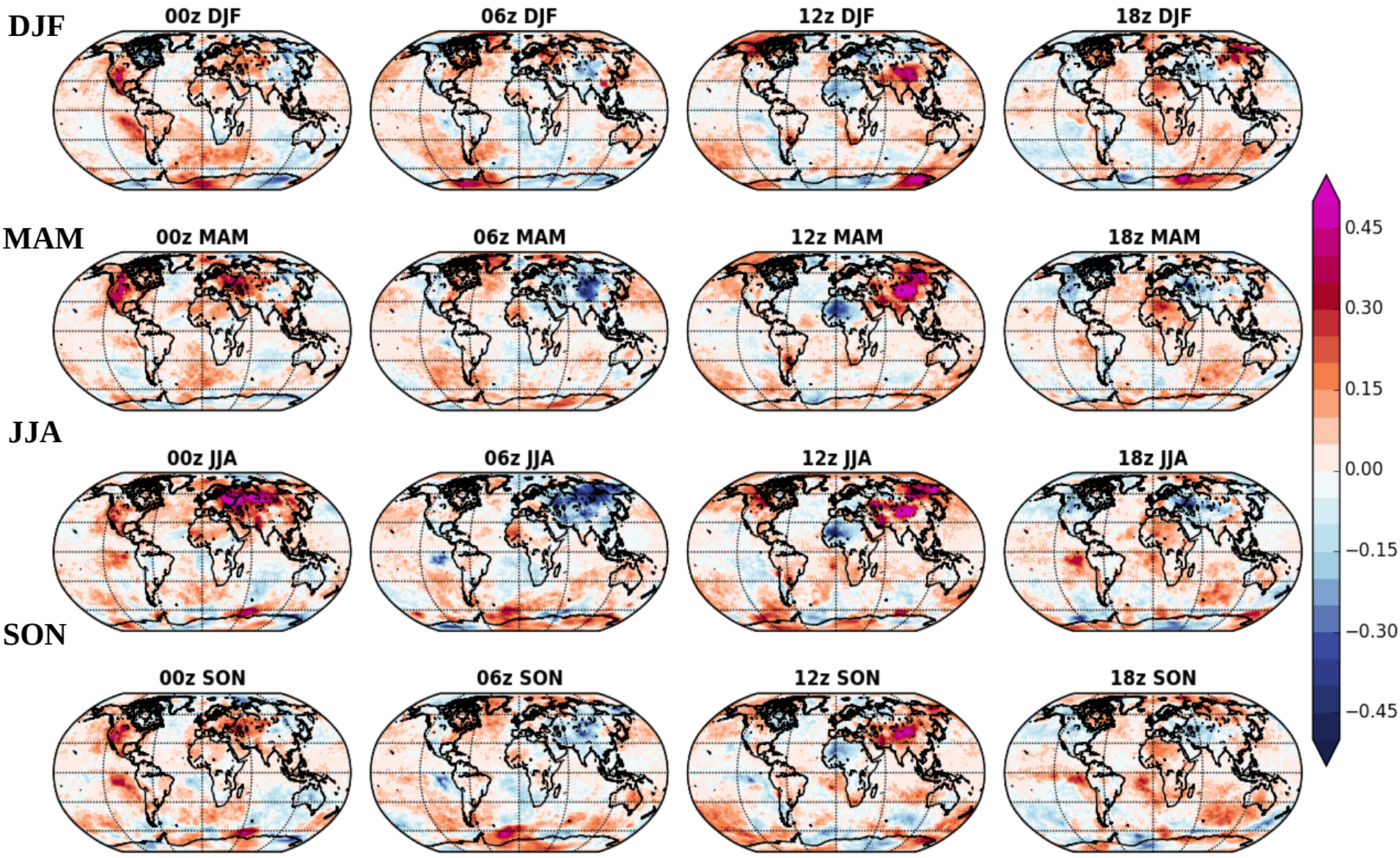
Findings

- Estimate the GFS systematic mean errors ✓
- Check the robustness of the seasonal averaged AI (2012 vs 2013 vs 2014)✓ Errors are robust
- Explore the errors in diurnal cycle
- Check if the low dimensional approaches can be used to correct the diurnal cycle errors
- Validate if errors can be explored at a resolution lower than operational

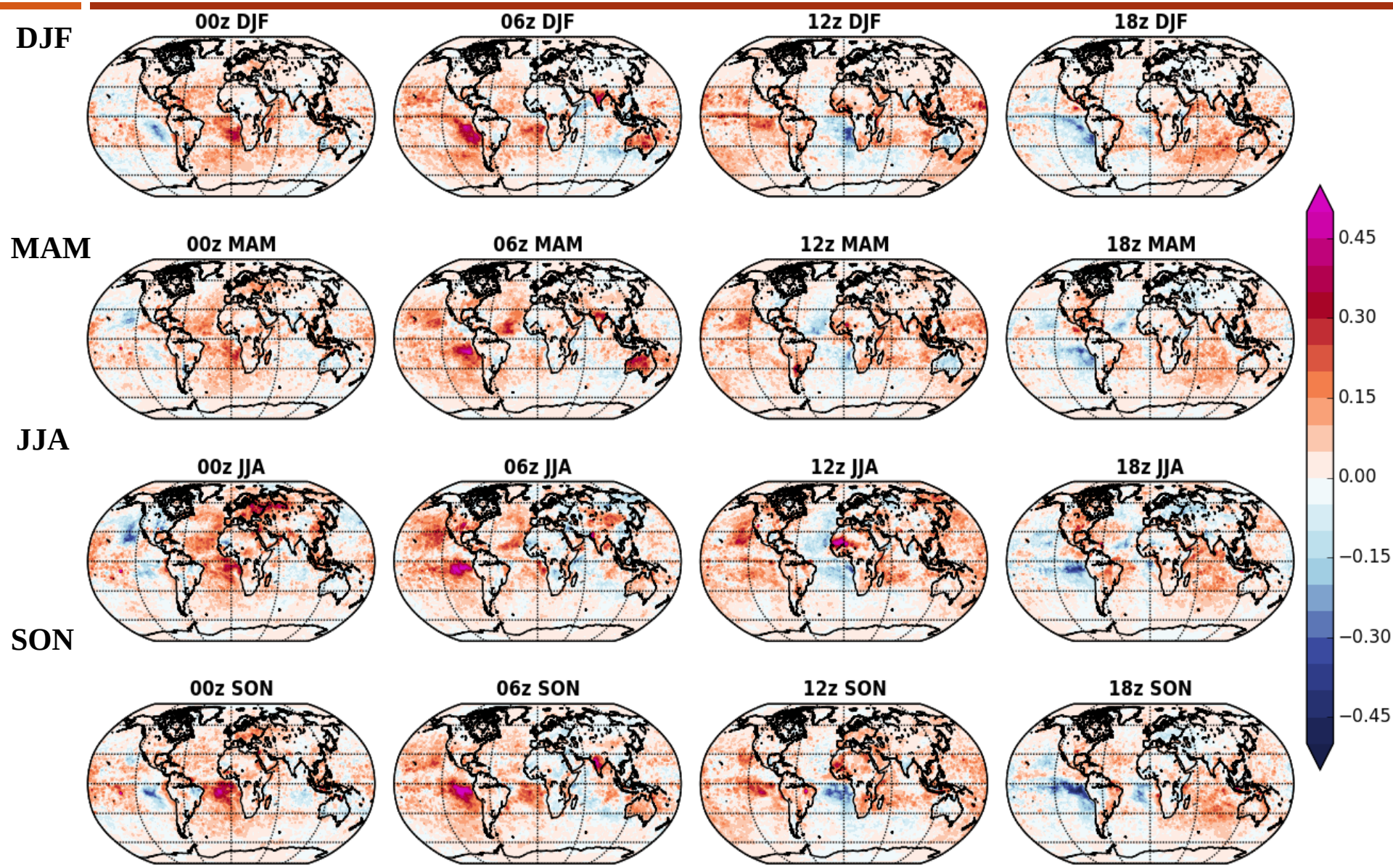
Diurnal cycle error estimation

- Compare the AI at 00, 06, 12 and 18Z
- Compute Empirical Orthogonal Functions (EOFs) of the AI anomaly
- Compare the diurnal cycle errors represented by the leading modes

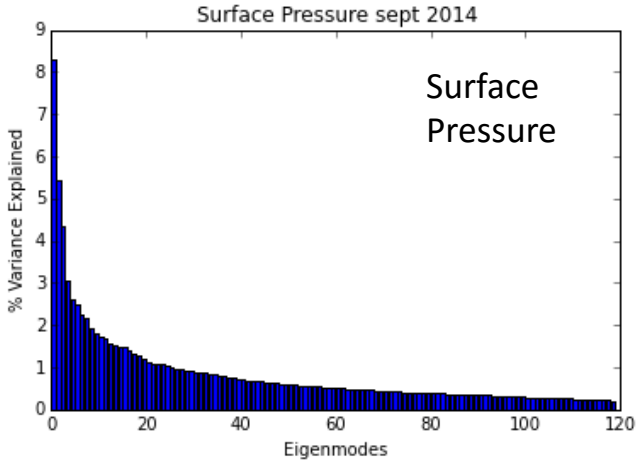
Mean diurnal cycle error: T (K) Sept ’14 at ~850mb

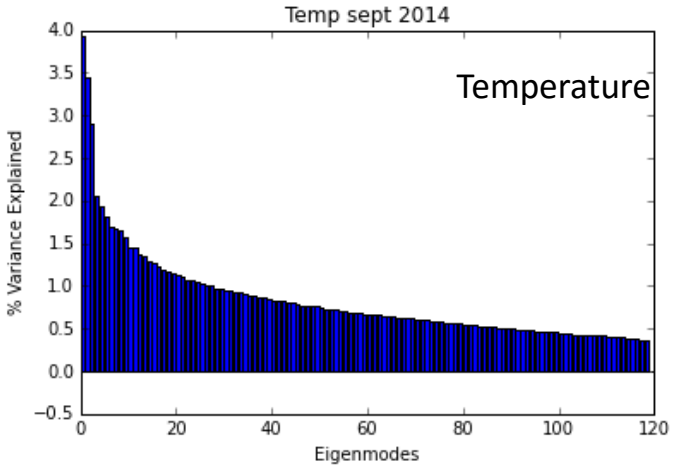


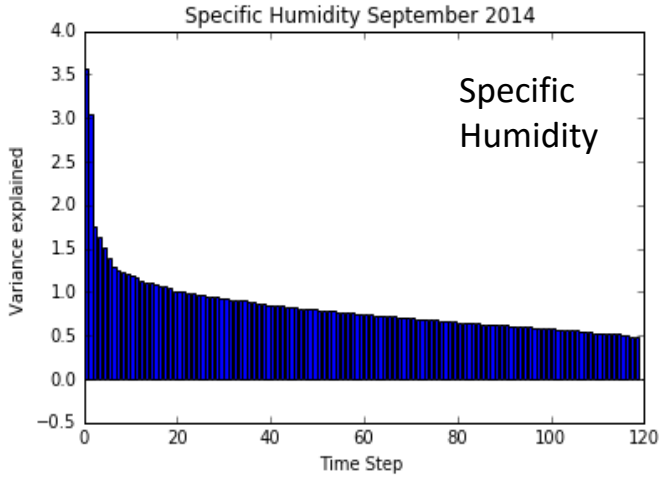
Mean diurnal cycle error: Q (g/kg) Sept '14 at ~850 mb



Variance Explained by Eigenmodes







Variance explained by first 4 modes

- Ps- 24%
- T- 11%
- Q- 10%

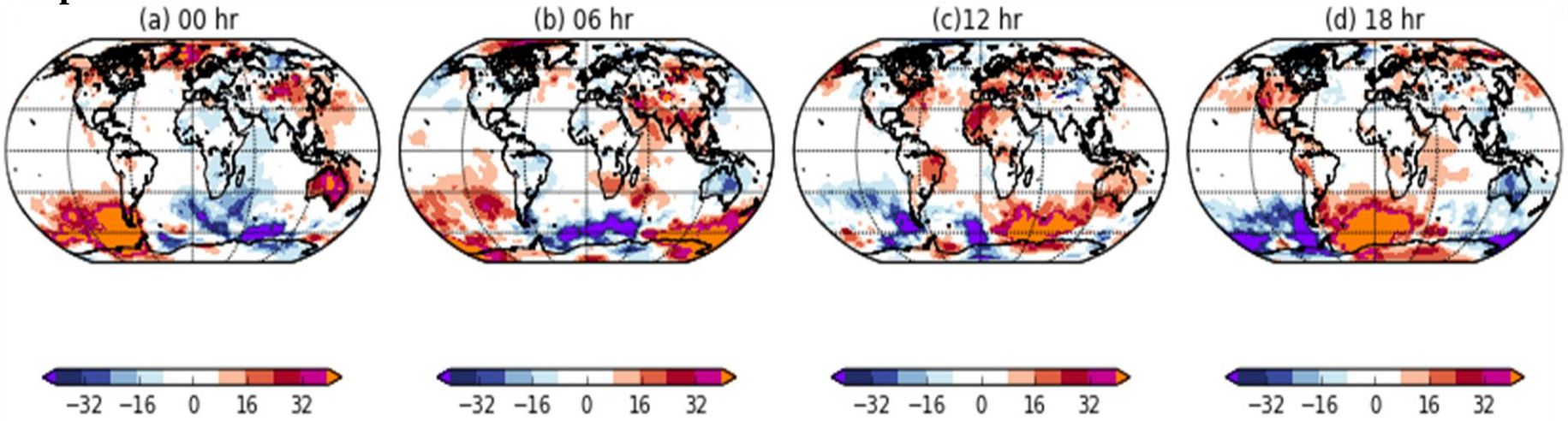
Diurnal cycles errors captured

Rest modes explain error due to other sources

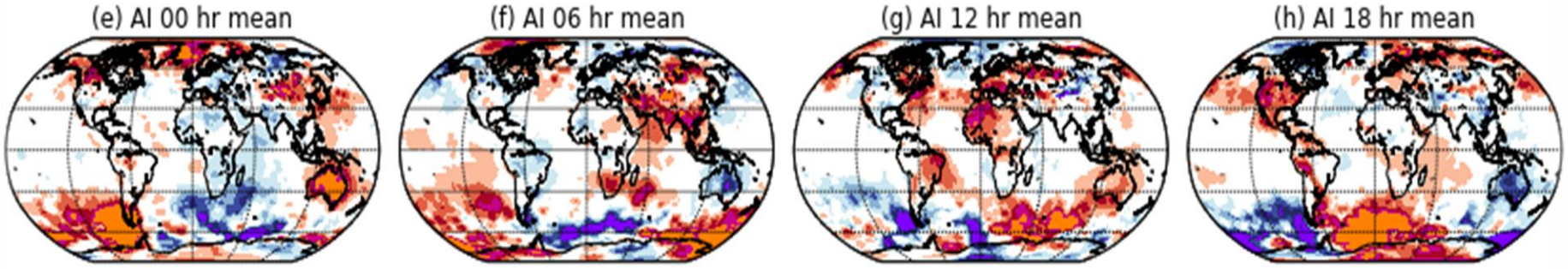
First four vs 120 modes: P_s (mb) Sept'14

First 4 modes capture the diurnal cycle errors almost perfectly

Top: 4 modes



Bottom: 120 modes



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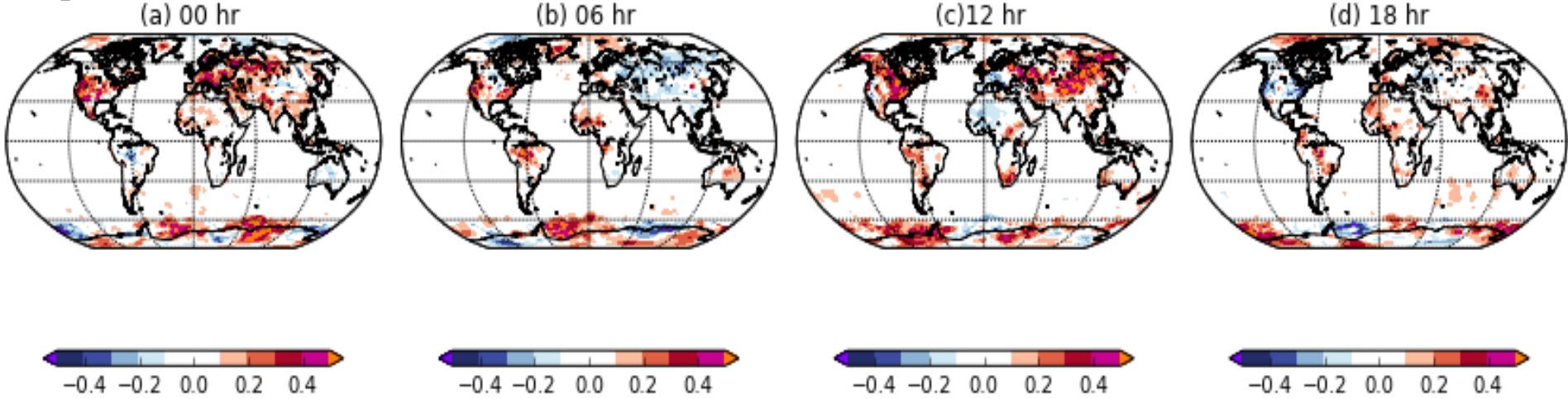
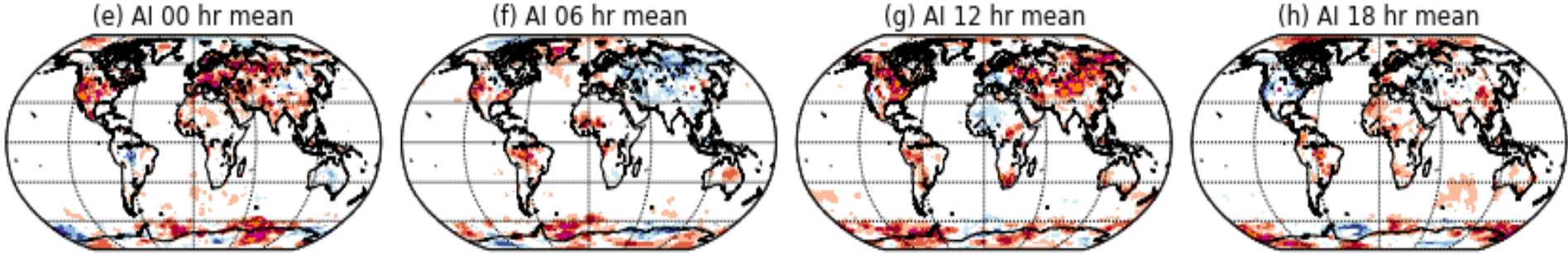


Bottom: 120 modes



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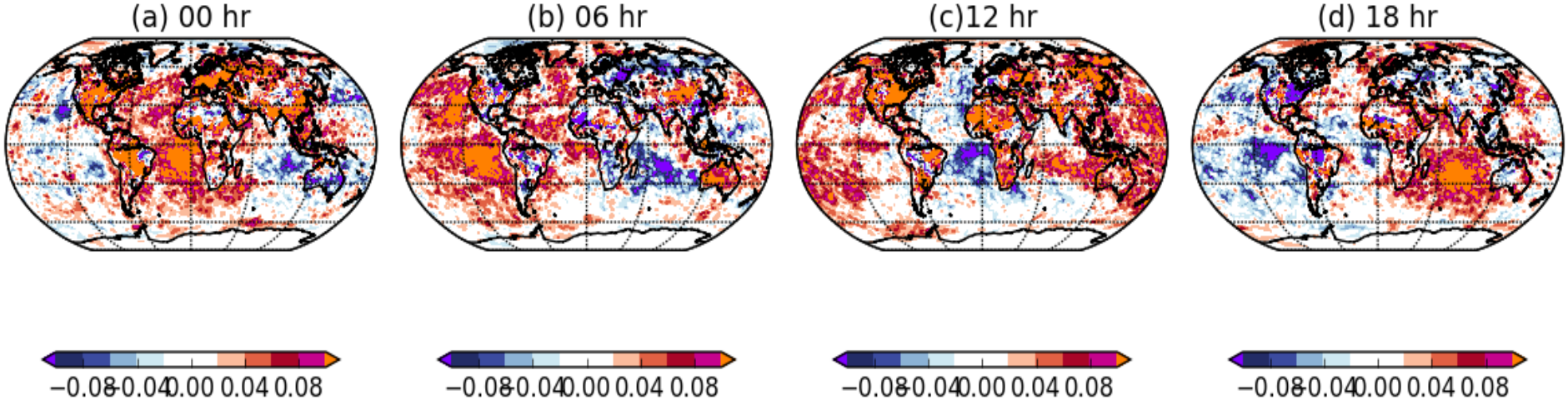

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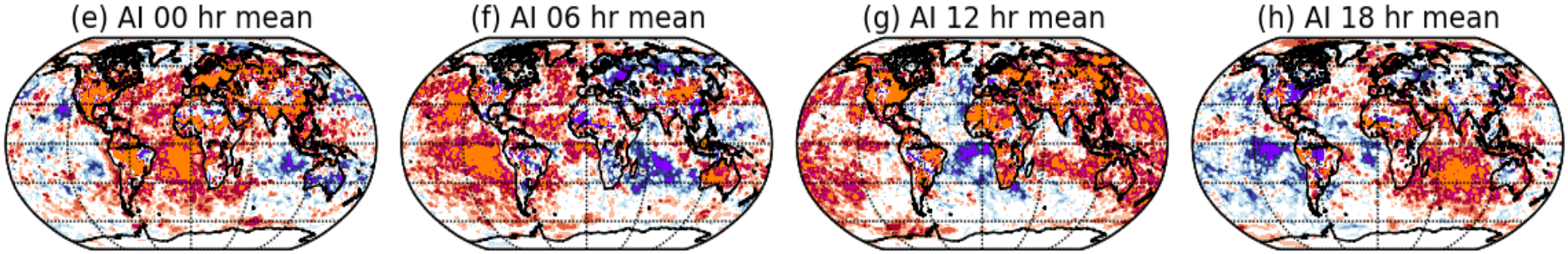

Findings

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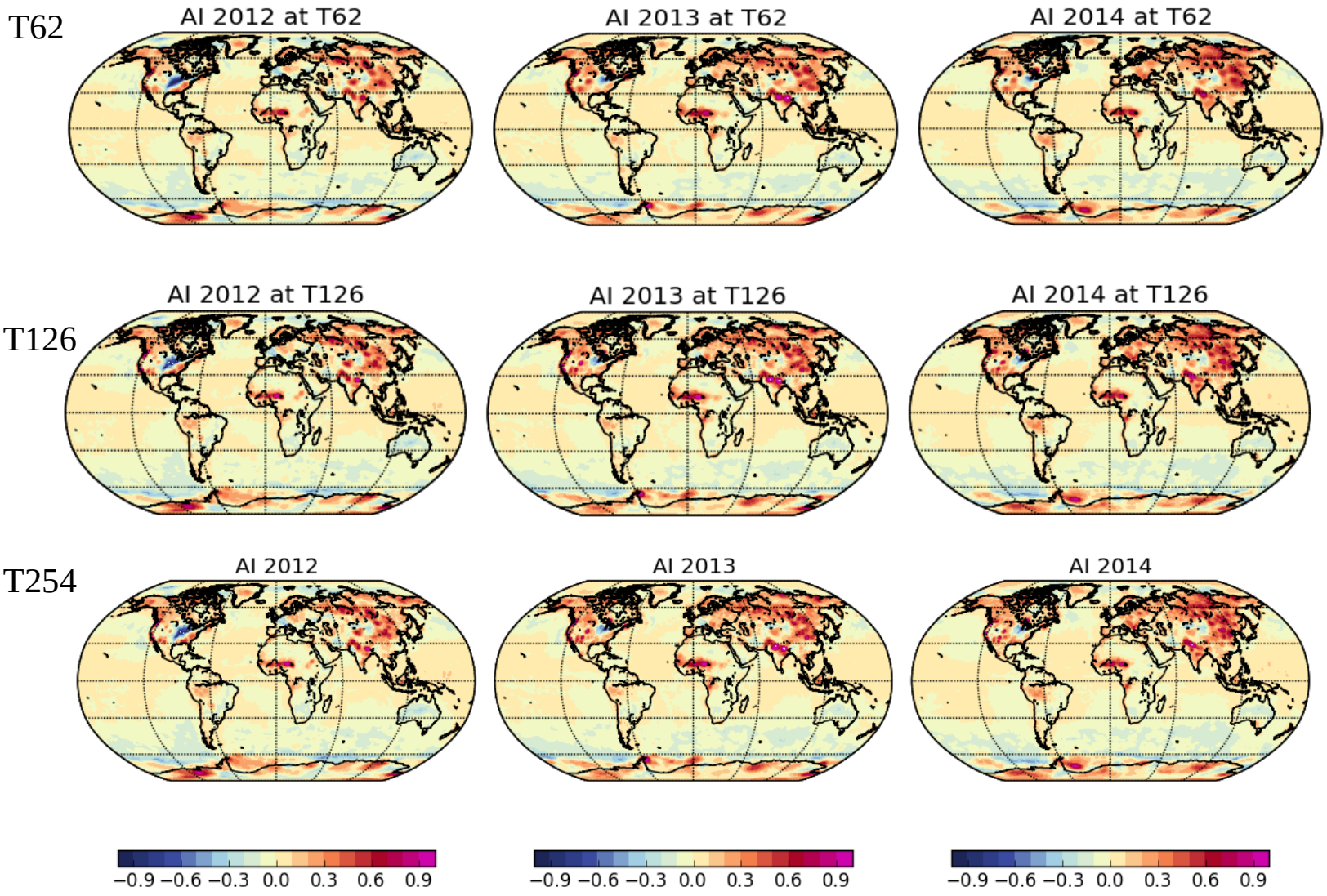
- Check the robustness of the seasonal averaged AI (2012 vs 2013 vs 2014)✓ Errors are robust
- Explore the errors in diurnal cycle ✓
- Check if the **low dimensional approaches** can be used to correct the diurnal cycle errors ✓ **Yes**, The errors in diurnal cycle represented with the first four modes are almost indistinguishable when compared with all (120) modes
- Validate if errors can be explored at a low resolution

Bias is independent of resolution



Projecting July 2014 mean Temperature AI at T62 (top), T126 (middle) and original T254 (bottom)

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- Check if the low dimensional approaches can be used to correct the diurnal cycle errors ✓ **Yes**, the errors in diurnal cycle represented with the first four modes are almost indistinguishable when compared with all modes
- Validate if errors can be explored at a low resolution ✓ Yes, the errors project project on low wave numbers

Proposed Plan to correct GFS

Proposed plans for GFS correction

- Apply online corrections to GFS
- Examine improvements in bias and random error
- Compare online correction results with standard operational statistical bias correction
- Use ensemble members as a testbed for corrections
- Work with the EMC scientists on how to facilitate testing impacts of new parameterizations

- Work with EMC scientists on R2O implementation

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Thank You!